# Turbulent Flow Predictions for Grid-to-Rod Fretting in Pressurized Water Reactors

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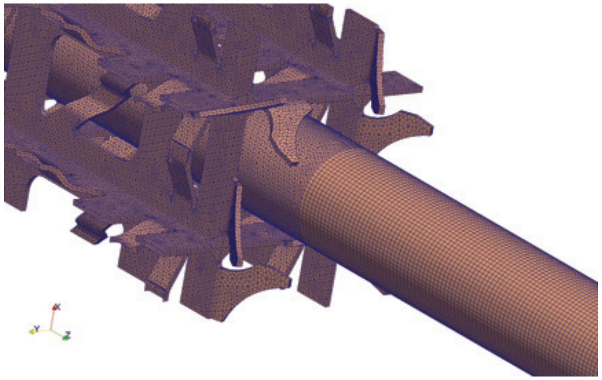
Computational fluid dynamics simulations are described for the grid-to-rod fretting (GTRF) problem that occurs within the core of a pressurized water reactor. The simulations are used to predict the turbulent excitation forces on the reactor fuel rods. These forces vibrate the rods and may result in rod wear and nuclear fuel leakage. A description of the overall GTRF problem is given here, along with sample turbulent-flow-simulation results.

Within the core of a nuclear pressurized water reactor (PWR), water flow is used to cool the fuel rods and extract thermal energy. The grid-to-rod fretting (GTRF) problem in such reactors is a flow-induced vibration problem that results in wear and failure of the rods. GTRF wear is one of the leading causes of leaking nuclear fuel and costs power utilities millions of dollars in preventive measures. In order to understand the root causes of such fuel leaks, this research investigates the complex turbulent coolant flow around a fuel-rod bundle. Ultimately, our goal is to accurately predict the turbulent excitation forces on the fuel rods, along with the coupled structural response of the rods and their supports. To date, it has not been possible to completely characterize the flow-induced fluid-structure interaction (FSI) problem for GTRF. Indeed, given the incompressible nature of the coolant, the relatively high Reynolds number, and the flexible character of the fuel rods and spacers, the FSI problem at the reactor core scale is daunting.

*Fig. 1. Surface mesh for 3×3 rod bundle. Only the center rod is shown, along with the grid spacer geometry.*



Our investigation centers on large-scale computational fluid dynamics simulations, using the Hydra-TH code, which is being developed by our team at LANL. Hydra-TH has the capability of computing high Reynolds-number turbulent flows over complex geometrical objects. There are tens of thousands of fuel rods in a PWR, and to compute the flow over all of them simultaneously, with the fidelity required for GTRF, is not feasible on today's computers. Instead, this study concentrates on a representative 3×3 rod bundle, for which a sample computational mesh is shown in Figs. 1 and 2. The 3×3 geometry was extracted from a 17×17 fuel assembly that is found in a typical PWR. There is a large degree of symmetry in the fuel assembly, which makes this geometrical simplification a reasonable approximation. The coolant flow generally moves axially down the outside of the fuel rods. A "grid spacer" (rod support structure) is also shown, which contains mixing vanes that stir the flow in order to enhance heat transfer from the rod to the coolant flow. This stirring, along with the high Reynolds number of the flow, results in a complex turbulent flow that is difficult to predict accurately.

Figures 3 and 4 show sample results from Hydra-TH, using the detached-eddy simulation (DES) turbulence model. In Fig. 3, vortex structures generated by the mixing vanes are shown as they transport down the rod. At an axial location downstream of the grid spacer, a cross-cut of the flow is shown in Fig. 4, where the details of the vortex structures are readily apparent. Although these vortex structures enhance the needed cooling, they also result in pressure fluctuations on the surface of the fuel rod, which in turn causes the fuel rods to vibrate. These vibrations cause the supports for the fuel rod to wear into the protective cladding on the surface of the rod, which, given enough time, may expose the internal nuclear fuel and result in a fuel leak. Understanding these interactions is critical to mitigating issues with GTRF. (For more examples and details on these calculations, see [1].)

Future work on GTRF will focus on coupling in the structural response of the fuel rods, along with coupling with wear models being developed by collaborators in the Consortium for Advanced Simulation of Light Water Reactors (CASL) project, which include research staff from MST and T divisions at LANL. The largest mesh run to date for the 3×3 problem is approximately 12 million elements. In order to adequately resolve the turbulent flow features, we believe a mesh of 100 million to 1 billion elements will be required. To adequately resolve the temporal

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fluctuations, necessary to predict the vibration of forces on the rod, a large eddy simulation of the turbulent flow will be performed. The time-dependent nature of the flow, complex geometry, and high Reynolds number drives the requirement for large meshes. Generation of these meshes is currently underway. To address flows with boiling, multiphase flow models are also being developed for implementation in the flexible Hydra-TH software toolkit.

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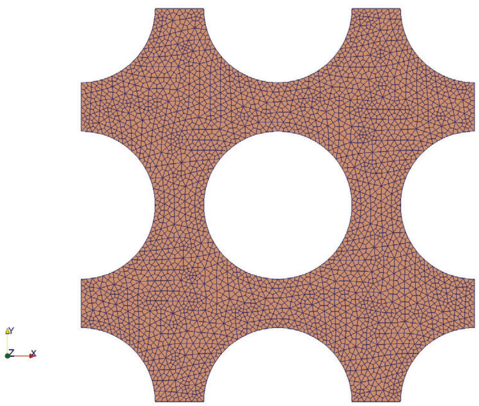

*Fig. 2. Axial cross-section of computational mesh of coolant channels for a 3×3 rod bundle, downstream of the grid spacer.*

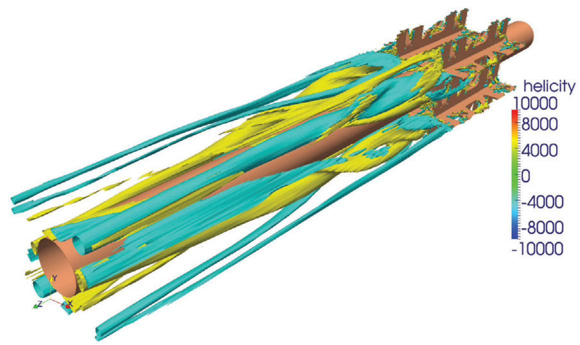


*Fig. 3. Instantaneous isosurfaces of helicity for the 3×3 rod bundle problem.*

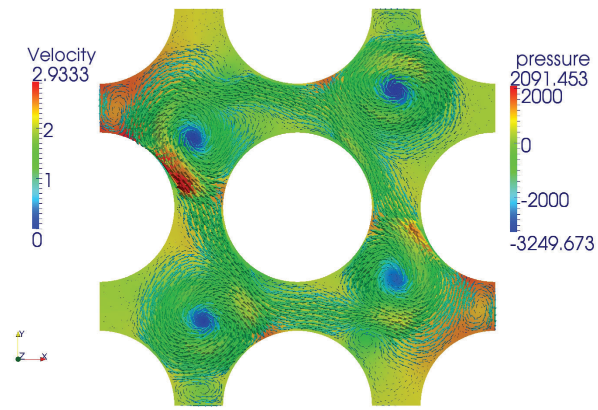


*Fig. 4. In-plane velocity vectors, shading colored by pressure value, at an axial location just downstream of grid spacer, corresponding to results in Fig. 3. Mixing vanes at the grid spacer.*

[1] Christon, M.A. et al., "Initial Assessment of Hydra-TH Code on GTRF Problems," LANL Report LA-UR-11-07034 and CASL milestone L2:THM.P4.01 (2011).

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